U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
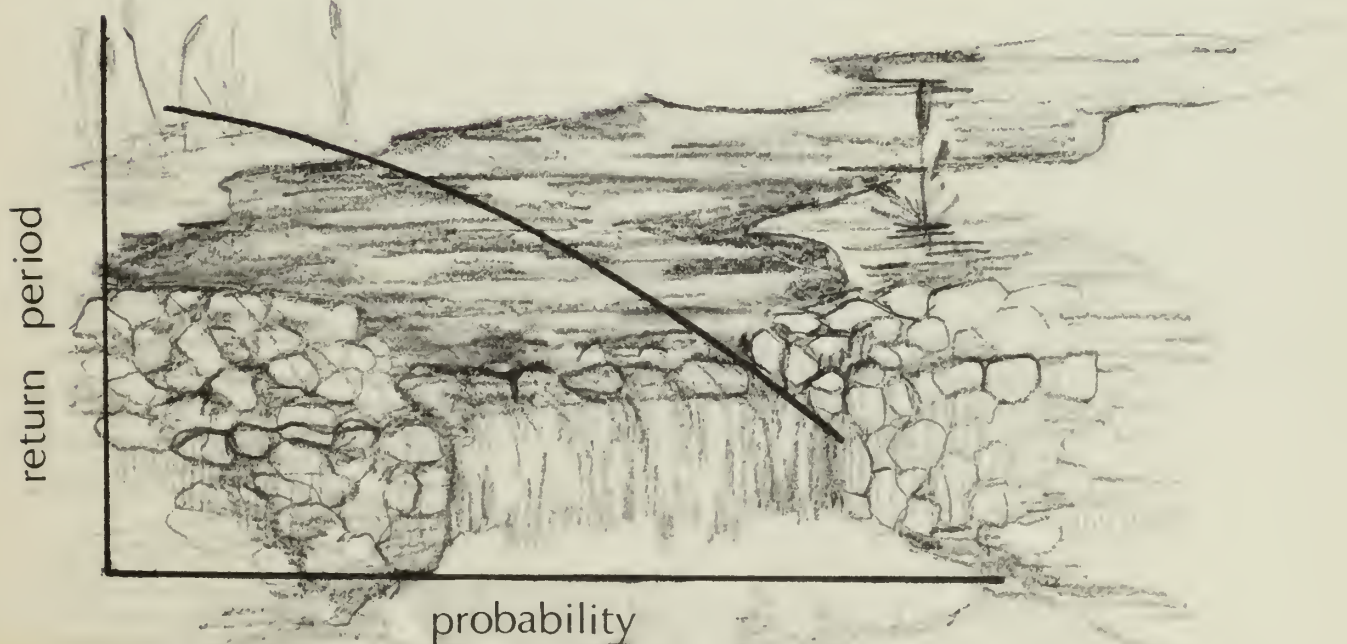
TECHNICAL NOTE

U.S. DEPARTMENT OF THE INTERIOR — BUREAU OF LAND MANAGEMENT

Hydrologic Risk and Return

Period Selection for Water Related Projects

by

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FOREWORD

This Technical Note provides guidance to the hydrologist (and other
specialists involved with water projects) who is or may be faced with
the task of determining a design hydrologic event for a project that
involves a hydrologic risk, such as bridges, culverts, land treatments,
fish habitat improvements, watershed management projects, etc. Included
is a discussion of hydrologic risk that defines both the manager's and
hydrologist's roles in determining risk levels for BLM-funded projects.
An extensive section on frequency of hydrologic events is included for
the hydrologist, followed by a section on guidelines and graphical aids
for determining return periods. The latter section includes problem-oriented
examples of return period selection.

Flood frequency analysis is only briefly discussed. This subject
will be covered in detail in a forthcoming BLM Technical Note.

INTRODUCTION

Hydrologists are frequently asked to provide design flows or stages for spillways, bridge openings, culverts, diversion dams, waterways, fish improvement structures, watershed improvement projects, and land treatment measures. Too often a return period or recurrence interval is arbitrarily chosen or a standard return period is used by the hydrologist.

The design event chosen by the hydrologist should be based on the risk of failure rather than on an arbitrary or predetermined return period, incorporating the fact that risk increases with increasing project life.

Since failure of a structure exposes the Federal government to potential liability claims, the acceptance of a certain level of risk of failure represents an important management decision.

The purpose of this Technical Note is to assist the hydrologist in understanding hydrologic risk and in communicating this understanding to the land manager. Secondly, with the statistical relationships and tables and graphs included in it, this Technical Note should serve as a reference for the hydrologist and other specialists involved with water-related projects where the frequency of hydrologic events is a concern.

ACCEPTANCE OF HYDROLOGIC RISK AS A MANAGEMENT RESPONSIBILITY

In water-related projects or structures, risk is equivalent to the probability of failure of the structure. The total risk of failure is made up of both hydrologic risk and structural risk. Structural risk refers to the probability that a structure will fail during an event of lower magnitude than the design event. Hydrologic risk is composed of the true or basic risk, which is due to the vagaries of nature, and uncertainty, which is a function of measurement inconsistencies, loss of information during analysis, or non-homogeneity of the data in time.

If we assume that structural risk is zero or near zero for hydrologic events not exceeding the design event, and that hydrologic uncertainty can be handled with confidence limits in the frequency analysis, then the remaining unknown variable is basic hydrologic risk. For large projects, the manager may want to conduct an elaborate study of the economically and politically optimum design for the project. This can be done as shown in Figure 1. The construction costs include the total cost of building the structure averaged over the expected project life plus annual maintenance costs. The risk costs include all those costs that would be incurred should the project or structure fail. For projects that impound water, these costs should include project replacement costs, downstream damage costs, liabilities from deaths and injuries, environmental damages, and the associated inconveniences and political consequences of project failure. The optimum design, from Figure 1, is where the construction cost balances the risk cost.

For small projects, the manager must still weigh the cost of constructing the project against the risk cost and attempt to minimize both. For example, constructing a stream stabilization structure to withstand a 50-year flood event is more expensive than designing it for a 10-year flood event. However, the environmental consequences of the structure failing at the 10-year design level (approximately five times more frequently) may dictate designing for the 50-year flood. On the other hand, where the costs of failure are negligible, as in a secondary road culvert, the manager can easily accept a much higher risk, on the order of 10 to 20%. Acceptance of a given hydrologic risk, say 5%, means the manager is 95% confident that the associated hydrologic event will not be equalled or exceeded in the stated time period, and that the structure or project will not fail for hydrologic reasons.

FIGURE 1

AVERAGE ANNUAL COSTS FOR DIFFERENT PROJECT DESIGNS
(Example only)

PERCENT PROBABILITY OR RISK OF FAILURE
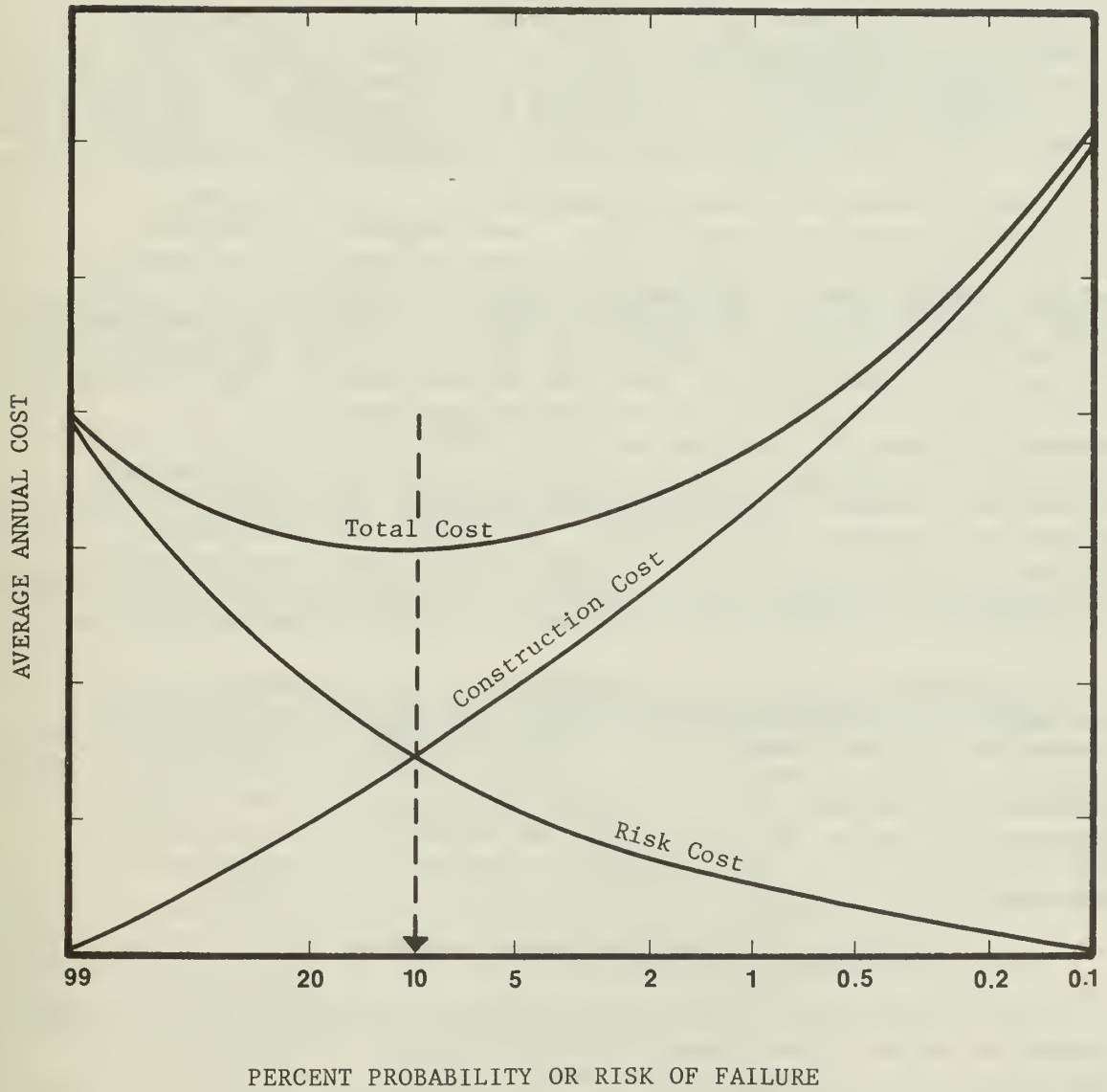
Many laymen and occasionally some hydrologists become confused about the real meaning of storm or flood return periods. For example, the commonly referred to 50-year storm does not mean that there will be one and only one such storm every 50 years. In fact, there is only a 37% chance that the 50-year storm will be equalled or exceeded only once in any 50-year period. There is a nearly equal (36%) chance of experiencing no such storms in the same period. Furthermore, there is a 19% chance of experiencing exactly two such events in fifty years. Another way of interpreting the meaning of a 50-year event is to say that there is a 1/50 or 2% chance of equaling or exceeding the 50-year event in any one year and, conversely, a 98% chance of non-occurrence in any one year.

It must be reiterated that the probability of event occurrence increases with increasing project life. The decision on the physical life of a project is an important one and must be taken into account in selecting a design event. For example, contour trenches that have been designed to handle the 75-year storm have only a 6% chance of experiencing one or more equal or larger storms in the first five years of their life, but by the twentieth year this risk has increased to 24%. Selecting a project life, as in determining acceptable hydrologic risk, is a management decision which relies heavily on specialist recommendations. In selecting the effective life of a project or structure, the manager must take into account the fact that risk increases with project duration. What are the objectives of the project? Do project benefits decrease over time or are they constant or cumulative with time? Can the project be discontinued (structure taken out) when project objectives are met? All the above factors should be evaluated and considered in the decision.

The respective roles of the specialist and the land manager in determining the acceptable hydrologic risk have been discussed briefly. To summarize, the land manager must ultimately decide on the level of risk that the BLM will accept for any project. The specialist is responsible for ensuring that the manager understands the statistical relationships involved and the factors that determine both the risk and project life decisions. These decisions along with the specialist's recommendations should be well-documented in the official files.

FREQUENCY OF HYDROLOGIC EVENTS IN NATURE

Several questions are often asked about the probability of occurrence of events in nature. Most common are the following: (1) What is the probability of encountering such an event in a single year? (2) What is the probability of encountering the event in a period of years? and (3) What is the probability of encountering more than one such event in a period of years? All these questions can be answered with the help of the binomial distribution,

$$f(x) = \frac{N!}{x! \ (N-x)!} \ p^x(1-p)^{N-x}$$

(1)

which is found in any standard statistical or mathematical probability text. The binomial distribution has tremendous value in hydrologic studies.

As used in hydrology, the terms return period and recurrence interval are synonymous. They are defined as the average time interval between actual occurrences of a hydrologic event of a given or greater magnitude. The reciprocal of the return period or recurrence interval is the probability of exceedance, expressed mathematically as

$$p = \frac{1}{T}$$

(2)

where T, the return period, is most often expressed in years and p, the probability, is dimensionless. The probability of non-occurrence (q) is further defined as

$$q = 1 - p = 1 - 1/T$$

(3)

If T is in years then p represents the probability of the T-year event (or a greater event) occurring in any one year.

Example: The 100-year flood has a probability of .01 or 1% of occurring and a probability of .99 or 99% of not occurring in any one year.

Now we can use the binomial distribution to give us some valuable probability information about the frequency of hydrologic events. The binomial distribution is rewritten as:

$$P = p^i(1-p)^{N-i} \ \frac{N!}{i(N-i)!}$$

(4)

where P is the probability of obtaining exactly i events in N years, with i having a probability of p of occurring in any single year. Remember that an event is one that either equals or exceeds the given event. We can use equation 4 to give some interesting probability information about the 100-year flood:

Example 1: What is the probability of experiencing only one flood in 100 years that equals or exceeds the 100-year flood?

Answer: The probability of one and only one event equal to the 100-year flood occurring in 100 years is 37% or 37 chances out of a 100.

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Example 2:   What is the probability of experiencing no floods equal
               to or greater than the 100-year flood in a 100-year
               period?
Answer: Equation 4 reduces to

$$P = (1-p)^N \text{ or } q^N \tag{5}$$

               The probability of no 100-year events occurring in 100
               years is 37%.

    We can use the complement of equation 5 to find out the probability
of experiencing <u>one or more</u> events equal to or greater than the 100-year
event in a 100-year period, or

$$P = 1 - q^N \tag{6}$$

From Example 2, $P = 1 - .37$ or $p = 63\%$

Equation 6 was used to construct the following table of probabilities:

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Table 1. Percent Probability of Occurrence of One or More
Events Equal to or greater than the T-year event
in N years.

No. of Years (N)	Return Period (T), Years											
	5	10	20	25	50	75	100	200	500	1000	5000	10,000
5	67	41	23	18	10	6	5	2	1	*	*	*
10	89	65	40	34	18	13	10	5	2	1	*	*
20	99	88	64	56	33	24	18	10	4	2	*	*
25	**	93	72	64	40	29	22	12	5	3	*	*
50	**	**	92	87	64	49	39	22	10	5	1	*
75	**	**	98	95	78	63	53	31	14	7	1	1
100	**	**	99	98	87	74	63	39	18	10	2	1
200	**	**	**	**	98	93	87	63	33	18	4	2
500	**	**	**	**	**	**	99	92	63	39	10	5
1000	**	**	**	**	**	**	**	99	86	63	18	10
5000	**	**	**	**	**	**	**	**	**	99	63	39
10,000	**	**	**	**	**	**	**	**	**	**	86	63

** greater than 99.5%   * less than 1%

Occasionally the hydrologist may want to know the probability of experiencing multiple numbers of events equal to or greater than the return period event.

Equation 4 was used to construct the following table of probabilities related to the 100-year flood:

Table 2: Percent Probability of Occurrence of the 100-year flood.

No. of Years (N)	Number of Events (i)				
	0	1	2	3	1 or more
100	37	37	18	12	63
50	61	31	8	2	39
25	78	20	2	*	22
10	90	9	*	*	10
5	95	5	*	*	5
1	99	1	*	*	1

* less than 1%

Tables 1 and 2 can be used for any set of hydrologic data developed from discrete hydrologic variables, such as streamflow stage or discharge, lake levels, groundwater levels, precipitation, evaporation, etc.

SELECTING THE RETURN PERIOD OF A HYDROLOGIC EVENT

Given the risk level and the project life, the hydrologist can compute the return period from Equation 4 by solving for P. Since this is an unwieldly computation, three graphs have been prepared to make this determination simple. Figure 2 is used to determine the return period corresponding to the risk of experiencing at least one event equal to or greater than the return period event in N years. Figure 3 should be used where the interest is in two or more events equal to or greater than the return period event. Figure 4 is used where the interest is in three or more events equal to or greater than the return period event. Examples of the use of these graphs are shown below:

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Figure 2. Return periods corresponding to the probability
of experiencing one or more events equal to or
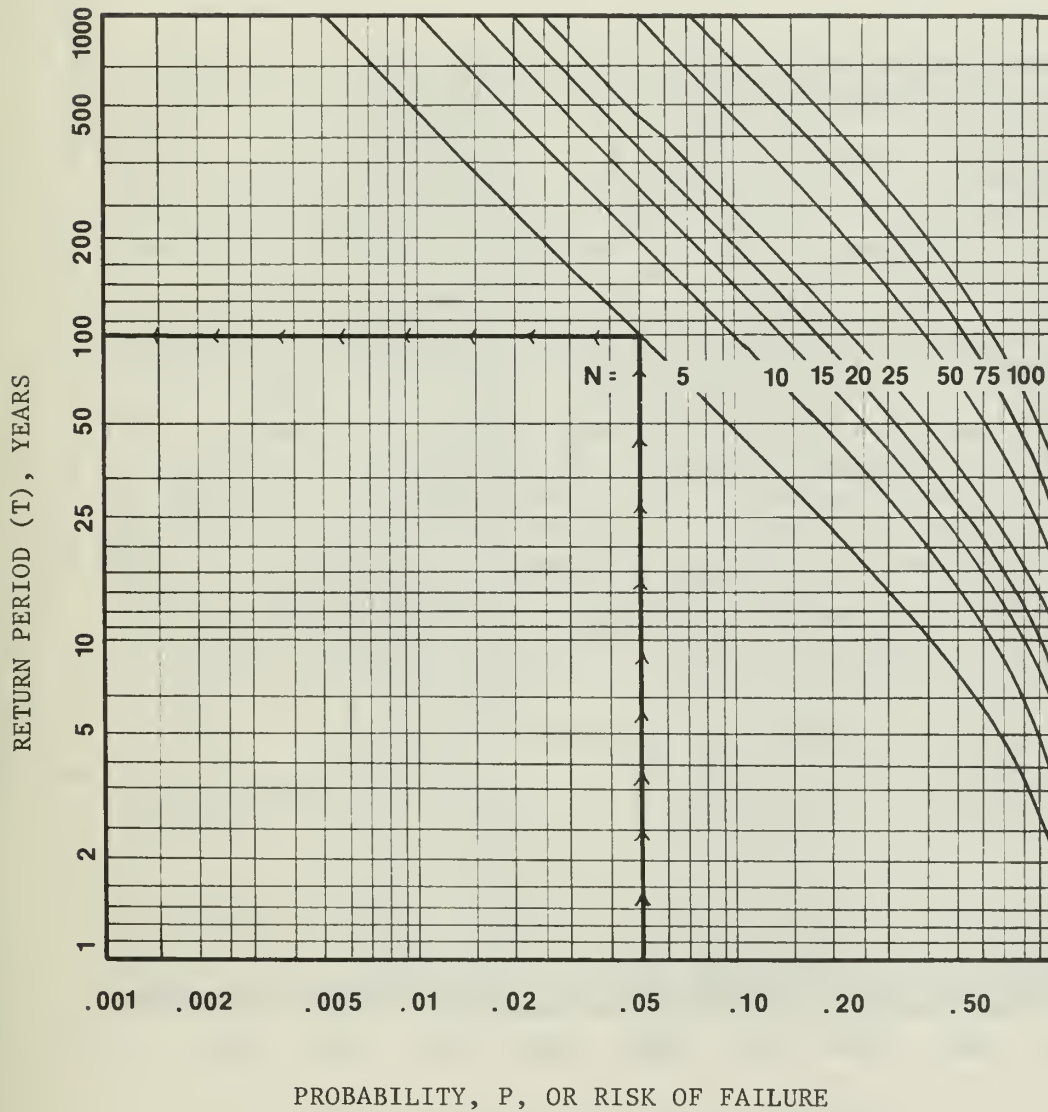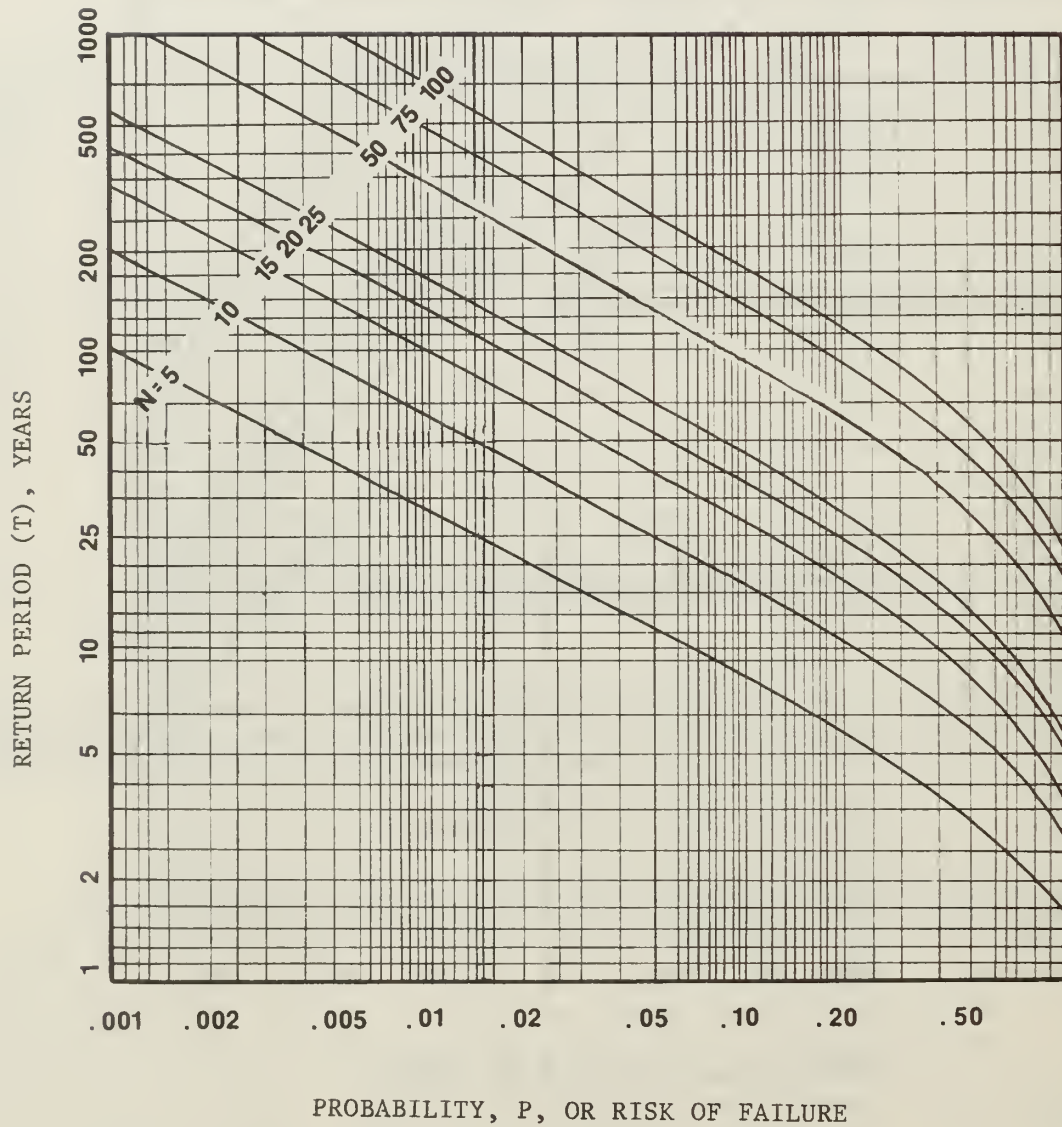greater than the T-year event in N years.

PROBABILITY, P, OR RISK OF FAILURE

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Figure 3. Return periods corresponding to the probability
of experiencing two or more events equal to or
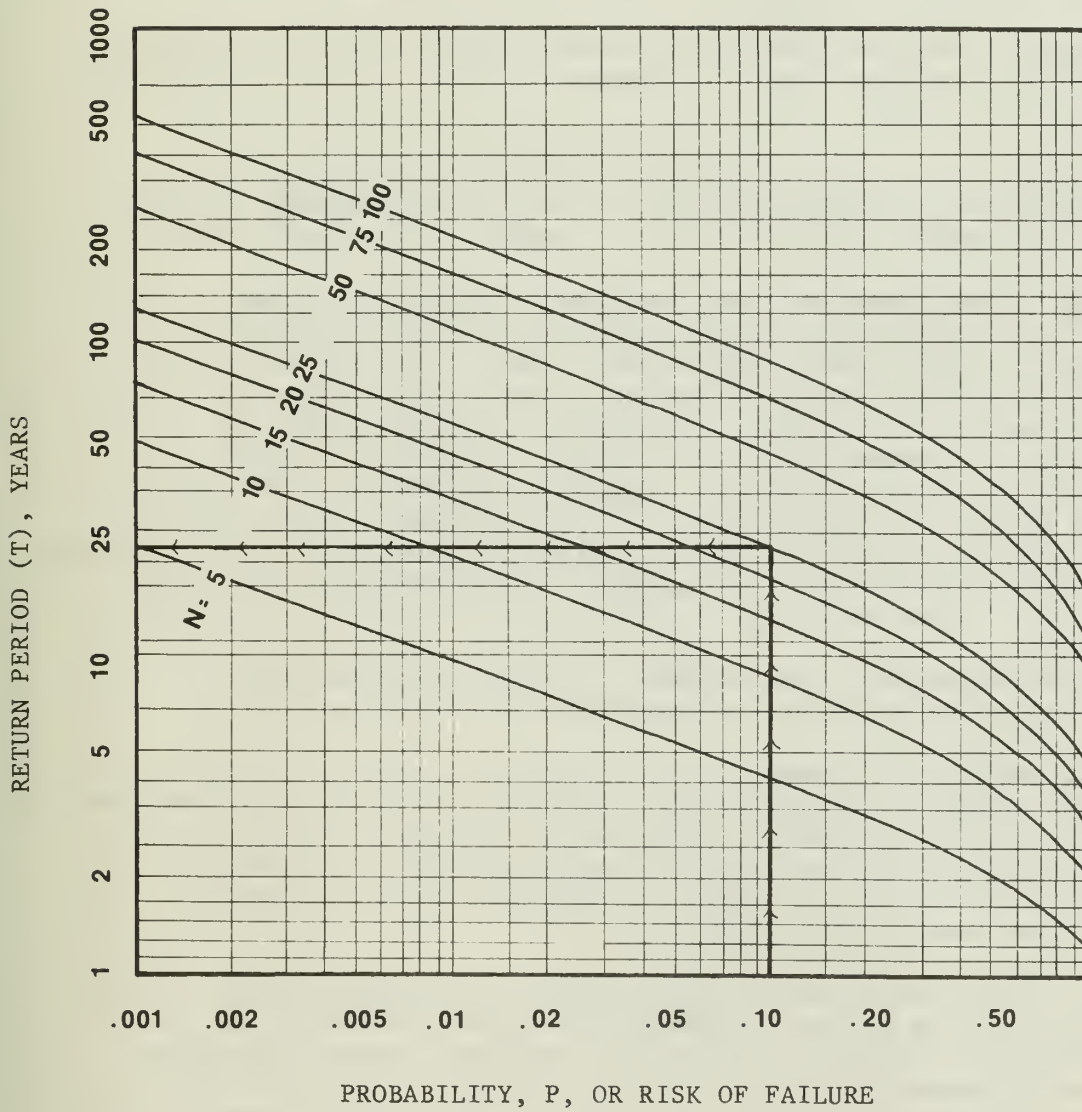greater than the T-year event in N years.

RETURN PERIOD (T), YEARS

PROBABILITY, P, OR RISK OF FAILURE

Figure 4. Return periods corresponding to the probability
of experiencing three or more events equal to or
greater than the T-year event in N years.

PROBABILITY, P, OR RISK OF FAILURE

Problem 1: A BLM district engineer has been asked to design and build a bridge suitable for use by logging trucks. The bridge will be designed to have a physical and economic life of five years, which is the duration of the associated timber sale contract. Failure of the bridge would not mean a great economic loss, but the associated channel damage and sediment problems created by a bridge failure would impact a critical downstream trout habitat. Because of the environmental hazards, the District Manager has decided on a risk level of 5%.

The hydrologist has been asked to provide a design Q for the project. Using Figure 2, he determines that the return period of the design event should be 100 years (p = .01).

The probability relationships given in this Technical Note are not restricted to flood frequency analyses. The following example relates to a low-flow problem incurred in a fish habitat improvement project.

Problem 2: A BLM hydrologist has been asked by his boss to assist in the hydrologic design of a fishery habitat improvement project. Specifically, he must design a spawning channel that will allow the spawners to easily migrate upstream, even in low flows. The project life has been set at 25 years. The fishery biologist feels that a risk level of 10% is reasonable for the project. Furthermore, he does not feel that the population would be damaged irretrievably if the channel failed to do its job twice within the 25-year period. By referring to Figure 4 the hydrologist can read directly the probability of experiencing three or more events equal to or greater than the T-year event. From Figure 4, the return period is 22.2 years or a probability of .045.

Once the return period is determined, the hydrologist must then calculate the event magnitude corresponding to that return period.

This event magnitude is taken from a frequency curve such as is determined through a log-Pearson Type III analysis. The Water Resources Council has published a set of guidelines for Federal agencies for determining flood flow frequencies at gaging stations (U.S. Water Resources Council, 1977). A good reference for general hydrologic frequency analysis is Kite (1976).

     To account for the uncertainty element of hydrologic risk, the data set should first be checked and adjusted for non-homogeneity or inconsistencies. All events used in the frequency analysis should be random and independent. If the record is made up of mixed populations, e.g., flood peaks created by different types of hydrologic events (snowmelt, rainstorms, rain-on-snow), special treatment of the data is indicated. Once a frequency distribution has been chosen and the data

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fitted to this distribution, confidence limits should be computed for the frequency curve, as explained in U.S. Water Resources Council (1977). The confidence level should be set by the hydrologist in accordance with the way he or she feels about the original data set. A confidence level of 95% is commonly used for most applications but is not a hard-and-fast rule. The upper confidence limit value then becomes the recommended design event for the project.

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